Effect of the dietary inclusion of *Camelina sativa* cake into quail diet on live performance, carcass traits, and meat quality

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ABSTRACT The present research studied the effect of the dietary inclusion of 3 different camelina (*Camelina sativa* (L.) Crantz) cakes on the live performance, slaughter traits, and breast meat quality of broiler quails (*Coturnix japonica*). With this purpose, a total of 480 fifteen-day-old broiler quails of both sexes were allocated to 48 cages (12 replicates/treatment, 10 quails/replicate) and received 4 dietary treatments: a control diet (Control), and 3 diets containing 15% of 1 commercial cultivar (Calena), and 2 improved lines (Pearl: low linoleic acid; Alan: low glucosinolates). During the experiment, individual live weight (**LW**) and cage feed intake were recorded to calculate body weight gain (**BWG**) and feed conversion ratio (**FCR**). At 35 d of age, quails were slaughtered, and carcasses were weighed and dissected to compute yields. On breast (*pectoralis major* muscle) the measurements and analyses considered ultimate pH, L*a*b* color values, proximate composition, oxidative status, cooking loss and WBSF toughness. Broiler quails receiving diets with camelina cakes exhibited mortality and health status similar to the control. However, growth performance was impaired in camelina-fed groups, especially for Calena ($P < 0.05$). Overall LW and BWG were slightly lower, whereas feed intake was slightly higher in camelina-fed groups compared to Control ($P > 0.05$). Therefore, higher FCR was recorded for camelina-fed groups compared to Control ($P = 0.0004$). Moreover, breast meat from Calena treatment displayed higher water ($P = 0.0170$), and lower lipid ($P = 0.0051$) contents compared to those of the Control group, while protein and ash content remained unaffected. Heme-iron content and oxidative status of breast meat were not influenced by the dietary incorporation of camelina ($P > 0.05$). The research outcomes indicated that camelina cakes can be used as an alternative feed ingredient for broiler quails' diets, without compromising carcass yields and meat quality. However, as 15% dietary incorporation worsened live performance, the ideal camelina cake inclusion level should be thoroughly investigated as well as a parallel research effort into further reducing glucosinolates content of camelina.

Key words: *Coturnix japonica*, improved camelina lines, *pectoralis major* muscle, heme-iron, lipid oxidation

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INTRODUCTION

Camelina sativa (L.) Crantz is an annual herbaceous crop belonging to the *Brassicaceae* family: it is commonly known as camelina, gold of pleasure or false flax. Camelina has been cultivated in Europe for centuries as a source of edible oil and used in popular medicine until the beginning of the twentieth century when it was replaced by more productive oilseed crops (Berti et al., 2016; Zanetti et al., 2021). In the last years, camelina has been rediscovered as a multipurpose crop due to its several favorable agronomic traits and its promising applications in feed, food, and the bio-based industry. Nowadays, camelina is cultivated in various countries as oilseed crop for biodiesel production, mainly as aviation fuel, thanks to its ability to reduce greenhouse gas emissions (Stamenković et al., 2021). Camelina can produce, at harvest, indehiscent siliques that can contain up to 20 small seeds (thousand kernel weight varies from 0.8 g to 1.8 g) with seed yields that can reach up to 3.3 Mg^{-1} in

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the European area (Obour et al., 2017). Normally, camelina seed oil (36−43% DM) is rich in polyunsaturated fatty acids (**PUFAs**), whose major contents are represented by α-linolenic acid (C18:3, ω-3) (>35% total fatty acids, **FA**) and linoleic acid (C18:2, ω-6) (>17% total FA). Among monounsaturated fatty acids (**MUFAs**), the eicosenoic acid (C20:1) (>19% total FA) is the most abundant followed by oleic acid (C18:1) (>14% total FA), while erucic acid (C22:1) is present in very small amount (<4% total FA). Additionally, the presence of bioactive compounds such as polyphenols and tocopherols are further distinctive differences from commonly used vegetable oils, as well as the presence of a good level of proteins and fibers (Kurasiak-Popowska and Stuper-Szablewska, 2020). However, camelina seed composition and quality are strongly influenced by sowing time, pedoclimatic conditions, and genetic characteristics (Berti et al., 2016; Zanetti et al., 2017, 2021; Angelini et al., 2020; Mondor and Hernández-Álvarez, 2021). The crop growth cycle is relatively short, varying from 90 d from sowing to harvest in spring sowing to 250 d if sowing is performed in autumn (Zanetti et al., 2021). From the agronomic point of view, camelina is characterized by low agricultural input requirements (Zanetti et al., 2017, 2021; Matteo et al., 2020), tolerance to common *Brassica* pests (Pachagounder et al., 1998; Deng et al., 2004) and diseases (Vollmann and Eynck, 2015), thus requiring less treatments, as well as resistance to drought and cold (Hunsaker et al., 2011, 2013). The wide environmental adaptability and the availability of both winter and spring cultivars, confer an enormous advantage to camelina over other emerging oilseed crops for the inclusion/integration into traditional crop rotations, primarily based on cereals or pulses (Chen et al., 2015; Mondor and Hernández-Álvarez, 2021). Other cropping strategies can be used for the inclusion of camelina in Europe: i) as main crop in marginal lands where the cultivation of other crop is not feasible (Bacenetti et al., 2017), ii) as cover crop in winter or summer cycles, replacing fallow (Leclère et al., 2018) and iii) as cash crop in double or relay cropping systems (Berti et al., 2015).

After camelina oil extraction from the seeds, the cake is obtained: it is a postpressing byproduct that contains 10 to 22% remaining oil, of which 30 to 35% is α-linolenic acid (ω-3). Moreover, camelina cake is also rich in crude protein (30−35%) with a good content of essential amino acids like leucine, valine, lysine, phenylalanine, and isoleucine (Colombini et al., 2014; Bătrîna et al., 2020). Thanks to all these positive features, camelina cake could be a promising alternative feedstuff for poultry diets (Orczewska-Dudek and Pietras, 2019; Untea et al., 2019; Lolli et al., 2020; Oryschak et al., 2020; Zając et al., 2020, 2021; Mondor and Hernández-Álvarez, 2021).

However, as all *Brassicaceae*, camelina seeds also contain several antinutritional compounds like glucosinolates, sinapine, condensed tannins, trypsin inhibitors, and phytic acid (Colombini et al., 2014; Russo and Reggiani, 2017). Glucosinolates are surely the most undesirable and, even if the content is lower (23−44 μmol/g) compared to the other *Brassicaceae*, it still exceeds the European regulation (EC Directive 2013/1275). When camelina cake was included in poultry diets, detrimental effects on live performance and nutrient digestibility were reported by several authors, which were attributed to a variety of reasons, including the content of glucosinolates and nonstarch polysaccharides (Ryhänen et al., 2007; Pekel et al., 2009, 2015; Thacker and Widyaratne, 2012). Other authors reported positive results on the fatty acid composition of the breast meat when the inclusion rate of camelina cake was 5 to 10% in broilers' diet (EFSA Report, 2008).

To further improve the nutritional profile of camelina cake and to lower the presence of antinutritional factors, 2 camelina lines: Pearl and F8CALG28 (Alan) have recently been released. Pearl line is characterized by reduced linoleic acid (C18:2, ω-6), thus enhancing the ω-3 fatty acids proportion for nutritional purposes (Zanetti et al., 2017) whereas the line Alan has a reduced glucosinolates content (Lolli et al., 2020), aiming to allow the use of camelina cake in monogastric animals at relatively high inclusion levels.

The aim of the present study was to evaluate the feasibility of a 15% *Camelina sativa* cake dietary inclusion for broiler quails. Furthermore, the possible effect of 3 different camelina lines (a commercial one, i.e., Calena, and 2 improved lines, i.e., Pearl and Alan) on live performance, carcass traits and meat quality of broiler quails was investigated. The choice of the Japanese quail for the study is linked to the fact that it is a poultry species of economic interest and because it has several positive productive characteristics, including fast growth, short generation interval, limited feed and space requirements, as well as desirable meat quality (Minvielle, 2004; Cullere et al., 2016, 2018; Dalle Zotte et al., 2019).

MATERIALS AND METHODS

Camelina Cakes

The 2 improved camelina lines, Pearl and Alan, characterized by reduced linoleic acid and glucosinolates content, respectively, were compared with the commercial variety Calena in an open-field trial carried out at the Experimental Centre of University of Bologna (Italy). At full maturity, camelina seeds were harvested and pressed. The obtained cakes were *vacuum* packaged and transported to the Department of Animal Medicine, Production and Health—MAPS (University of Padova, Italy) for analyses and subsequent inclusion in the experimental diets for broiler quails.

Experiment Design

The study was approved by the Ethical Committee of the University of Padova (Prot. n. 362845) and in accordance with the article 2, DL 4 March 2014, No. 26 of the Official Journal of the Italian Republic, implementing the EC Directive 86/60963/2010 EU regarding the

Table 1. Ingredients of the experimental diets (g/kg as fed).

Item	Experimental diets			
	Control	Calena	Pearl	Alan
Ground corn	450	457	449	476
Soybean meal	377	343	333	345
Sunflower meal	66.7	15.3	28.5	0.00
Wheat bran	44.0	6.00	10.5	0.00
Wheat flour	17.0	0.00	0.00	0.00
Camelina cake	0.00	150	150	150
Soybean oil	16.0	0.00	0.00	0.00
Camelina oil	0.00	0.00	0.00	0.00
DL-Methionine	1.50	1.50	1.50	1.50
L-Lysine	0.50	0.50	0.50	0.50
Calcium carbonate	19.0	19.0	19.0	19.0
Dicalcium phosphate	1.00	1.00	1.00	1.00
NaCl	1.50	1.50	1.50	1.50
Sodium bicarbonate	3.30	3.30	3.30	3.30
Vitamin-mineral premix[1]	2.50	2.50	2.50	2.50

[1]Vitamin and mineral premix provided the following per kg of diet: vitamin A, 11,500 IU; cholecalciferol, 2,100 IU; vitamin E (from DL-tocopherylacetate), 22 IU; vitamin B12, 0.60 mg; riboflavin, 4.4 mg; nicotinamide, 40 mg; calcium pantothenate, 35 mg; menadione (from menadione dimethyl-pyrimidinol), 1.50 mg; folic acid, 0.80 mg; thiamine, 3 mg; pyridoxine, 10 mg; biotin, 1 mg; choline chloride, 560 mg; ethoxyquin, 125 mg; Mn (from $MnSO_4 \cdot H_2O$), 65 mg; Zn (from ZnO), 55 mg; Fe (from $FeSO_4 \cdot 7H_2O$), 50 mg; Cu (from $CuSO_4 \cdot 5H_2O$), 8 mg; I (from Ca $(IO_3)_2 \cdot H_2O$), 1.8 mg; Se, 0.30 mg; Co (from Co_2O_3), 0.20 mg; Mo, 0.16 mg.

protection of animals used for experimental and other scientific purposes. The trial was performed at the farm located in the Padova province (Italy), with which the MAPS Department has a scientific agreement. The experiment design consists of $n = 4$ treatments of different experimental diets: a control diet (Control), similar to the growing-fattening diet used in commercial quail farming, and 3 diets formulated to include the 15% of the 3 different camelina cakes: Calena, Pearl, and Alan. All diets were set up to meet the minimum energy and nutrient requirements of Japanese quails and to be as much isoenergy and isonitrogenous as possible (NRC, 1994). Diets were in mash form and provided *ad libitum* throughout the experiment. The inclusion levels were chosen based on previous study on broiler quails and chickens (Bulbul et al., 2015; Zając et al., 2020). The ingredients of the experimental diets are presented in Table 1.

Fifteen-day-old quails (*Coturnix japonica*) ($n = 480$) were individually weighed (initial live weight) and wing tagged with identification number. The quails were allocated to the 4 treatments in such a way that the average initial body weight was not different across the treatments, providing 12 replicates of 10 quails each. Quails were housed in battery cages with continuous access to water and feed. The environmental conditions of the room were monitored: the average RH and temperature were 81.0% and 19.5°C, respectively, and the adopted photoperiod was 16L:8D hours. Birds were fed with the experimental diets for 21 d.

Live Performances

Quails were individually weighed at 15, 25, and 35 d of age to determine daily weight gain, while feed intake per cage basis was weekly recorded to calculate feed conversion ratio (**FCR**). Also, quail health status and mortality were daily monitored along the trial.

Carcass Dissection, Breast Meat Physical Analyses

At 35 d of age, all the male quails/replicate/treatment were weighed and slaughtered at commercial slaughterhouse. Carcasses were subsequently air-chilled, stored at 4°C and transported to the MAPS Department. For each treatment, carcasses were weighed, and yields on the slaughter weight were subsequently calculated using carcass breast and leg weights. Color measurements were performed on the cranial and caudal part of the *pectoralis major* muscle with a portable colorimeter (Lightness—L*, redness—a*, yellowness—b* values; CIE, 1976) Chroma Meter CR-400 Minolta (Minolta Sensing Inc., Osaka, Japan). The pH was measured 24 h postmortem (pHu) with a portable pH meter (FG2-Five GoTM; Mettler Toledo, Greifensee, Switzerland) calibrated at pH 4.0 and 7.0. Color and pH values represented the average of 2 repeated measurements.

A total of 56 breasts (14 breasts/treatment) were then *vacuum* sealed by 12 and cooked in a water bath at 80°C until core temperature reached 74°C. Meat samples were cooled in an iced bath, gently dried with paper towel, and weighed to calculate cooking loss. Shear force was assessed with a TA-HDi Texture Analyzer (Stable Macro System, London, UK) on $n = 4$ cooked meat cores (diameter 1.25 cm) per sample, sheared perpendicularly to the muscle fibers direction with a Warner-Bratzler cell (100 kg load cell, 2 mm/s crosshead speed) fitted on the texture analyzer. Warner-Bratzler shear force (**WBSF**) was calculated by averaging 4 measurements per sample.

Chemical Analyses of Camelina Cakes and of Experimental Diets

The chemical composition of camelina cakes and of the experimental diets can be found in Tables 2 and 3, respectively. Analyses of camelina cakes and the experiments diets were carried out in duplicate using the Association of Official Analytical Chemists (AOAC, 2000) methods to determine DM (method no. 934.01), CP (method no. 2001.11), crude fiber (method no. 978.10), ash (method no. 967.05), starch (amyloglucosidase-α-amylase, method no. 996.11) contents. Ether extract (**EE**) was determined after acid hydrolysis (EC, 1998). Gross energy (**GE**) was measured with an adiabatic bomb calorimeter (ISO, 1998). Moreover, the fiber fractions were determined for camelina cakes according to the method by Goering and Van (1970), modified by Robertson and Van Soest (1981). For experimental diets, the calcium and phosphorus analyses were performed by ICP-OES (Spectro Ciros Vision EOP) after microwave digestion (AOAC, 2000: method no. 999.10).

Table 2. Chemical composition (g/kg, as fed), gross energy content (MJ/kg), and antinutritional compounds: phytic acid (μgPA/mg, defatted DM), condensed tannins (μg CE/mg, defatted DM), trypsin inhibitor TIU/mg, defatted DM), sinapine (μg/mg, defatted DM), and glucosinolates (μmol/g, defatted DM) detected in Calena, Pearl, and Alan cakes used to formulate the experimental diets.

	Camelina cakes		
Item	Calena	Pearl	Alan
DM	915	923	923
CP	273	274	300
Ether extract	248	276	237
Ash	43.3	39.1	52.3
Crude fiber	165	159	92.3
NDF	316	307	272
ADF	213	218	156
ADL	118	121	52.4
Starch	22.1	19.1	16.7
Gross energy	24.5	25.7	22.6
Phytic acid	29.6	29.0	32.6
Condensed tannins	2.83	1.56	1.86
Trypsin inhibitor	14.3	11.9	12.9
Sinapine	4.04	4.30	4.01
Glucosinolates	29.5	38.7	25.3

Abbreviations: ADF, acid detergent fiber; ADL, acid detergent lignin; CE, catechin equivalent; NDF, neutral detergent fiber; PA, phytic acid; TIU, trypsin inhibitor unit.

For the antinutritional compounds analyses, a representative aliquot of each cake and experimental diets was *vacuum*-sealed and sent to the Institute of Agricultural Biology and Biotechnology (**IBBA**), National Research Council (**CNR**), Milano (Italy). A total of 5 g of each camelina cakes and experimental diets were defatted twice with hexane (1:10, w/v). The defatted cake was dried and stored in the fridge at −20°C until use. Phytic acid, trypsin inhibitor, sinapine and glucosinolates (**GLSs**) were determined as reported in Pozzo et al. (2022). Condensed tannins were extracted from defatted cake with 70% acetone; all extracts were evaporated to dryness and then suspended again in 100% methanol. Condensed tannins were determined by the vanillin method using catechin as a standard (Price et al., 1978; Herald et al., 2014). The reaction time was 20 min in the dark and the absorbance was read at 500 nm.

Table 3. Proximate composition (g/kg, as fed), mineral (mg/kg, as fed) contents, metabolizable energy (MJ/kg, as fed), and antinutritional compounds phytic acid (μg PA/mg, defatted DM), condensed tannins (μg CE/mg, defatted DM), trypsin inhibitor TIU/mg, defatted DM), sinapine (μg/mg, defatted DM), and glucosinolates (μmol/g, defatted DM) of the experimental diets.

	Experimental diets			
Item	Control	Calena	Pearl	Alan
DM	884	893	895	892
CP	253	263	267	258
Lipids	32.2	63.2	65.0	65.6
Ash	72.4	70.5	67.7	68.5
Crude fiber	35.0	40.3	40.8	32.0
Starch	273	231	249	263
Ca	15.3	13.6	12.9	12.8
P	6.69	6.38	6.36	5.87
Ca/P	2.28	2.13	2.03	2.18
Metabolizable energy	11.7	11.7	11.7	11.7
Gross energy	16.6	17.4	17.5	17.2
Phytic acid	13.6	14.5	14.8	14.3
Condensed tannins	0.22	0.37	0.26	0.24
Trypsin inhibitor	nd	4.34	4.27	4.44
Sinapine	0.00	0.28	0.37	0.21
Glucosinolates	0.00	3.58	4.63	2.82

Abbreviations: CE, catechin equivalent; nd, not determined; PA, phytic acid; TIU, trypsin inhibitor unit.

Meat Proximate Composition

A total of $n = 144$ breasts ($n = 36$ breasts/treatment) were randomly ground by 3 within each treatment (to have enough sample matrix to perform all the scheduled analysis) with a Retsch Grindomix GM 200 (4,000 RPM for 9 s). Subsequently, meat samples were frozen at −40° C, freeze-dried and ground again (4,000 RPM for 5 s) to obtain a fine powder which was used to determine proximate composition. The proximate composition of meat was analyzed in accordance with the AOAC (2000) methods.

Meat Heme-Iron Content and Oxidative Status

A total of $n = 40$ breasts ($n = 10$ breasts per treatment) were ground with a Retsch Grindomix GM200 (4,000 RPM for 10 s) to evaluate the heme-iron content and oxidative status on fresh breasts. The heme-iron content was determined using the method described by Hornsey (1956) and was expressed as mg/kg of fresh tissue. The extent of muscle lipid peroxidation (thiobarbituric acid reactive substances—**TBARs**) was evaluated with a spectrophotometer (Hitachi U-2000; Hitachi, Mannheim, Germany) set at 532 nm, that measured the absorbance of TBARs against a 1,1,3,3-tetraethoxypropane calibration curve (Botsoglou et al., 1994). Oxidation products were quantified as malondialdehyde (**MDA**) equivalents (mg MDA/kg meat).

Statistical Analysis

Growth performance, carcass and breast meat traits, meat proximate composition, heme-iron content, and oxidative status were subjected to a 1-way ANOVA with experimental diet (Control, Calena, Pearl, and Alan) as fixed effect, following the GLM procedure of the SAS 9.1.3 statistical analysis software for Windows (SAS, 2008). Least square means were obtained using the Bonferroni test and the significance was calculated at a 5% confidence level. A chi-square test with Marascuilo (1966) procedure was performed on mortality to detect the differences among treatments.

RESULTS

Live Performances

Tables 4 and 5 show the effect of the dietary inclusion of camelina cakes on growth performance, feed efficiency

Table 4. Effect of the dietary inclusion of *Camelina sativa* cakes into broiler quails diet on live performance.

Item	Experimental groups					
	Control	Calena	Pearl	Alan	*P* value	RSD[1]
N.	120	120	120	120		
Live weight (g)						
15 d	119	119	120	120	0.8580	10.1
25 d	199[A,a]	190[B]	192[AB,b]	192[AB,b]	0.0053	20.9
35 d	259	254	257	255	0.2429	21.0
BWG (g/d)						
15−25 d	8.00[A]	7.09[B]	7.18[B]	7.30[B]	<0.0001	1.58
25−35 d	6.00[b]	6.49[a]	6.43[a]	6.30[a]	0.0162	1.28
15−35 d	7.00	6.76	6.82	6.85	0.1512	0.83

[1]Residual standard deviation.

[A,B]Means in the same row with different superscript letters differ for $P < 0.01$ and $P < 0.001$.

[a,b]Means in the same row with different superscript letters differ for $P < 0.05$.

and mortality of growing broiler quails. Considering the whole productive cycle, live weight and body weight gain were not affected by the dietary treatments (Table 4). However, body weight gain was negatively influenced by the presence of camelina cake (all treatment groups) in the first growth period (15−25 d), which showed lower values compared to the Control group ($P < 0.001$). In the second growth period (25−35 d), camelina-fed quails recovered the gap with the Control ones highlighted during the first part of the trial and displayed a higher body weight gain compared to the Control group ($P < 0.05$).

Results of Table 5 indicate that the dietary inclusion of Calena and Pearl cakes into quails' diet negatively affected feed intake compared to the Control group in the period 25 to 35 d ($P < 0.05$), while Alan exhibited intermediate values. Despite this, feed intake showed similar values among groups considering the whole trial. During the whole experimental period, FCR was negatively affected by the presence of camelina cake into quails' diet since Calena and Pearl displayed higher values than the Control, with Alan having an intermediate value ($P < 0.001$): this result was attributable to the first part of the rearing cycle (15−25 d; $P < 0.001$), as in the second period (25−35 d) no significant differences among groups were highlighted for this parameter.

Table 5. Effect of the dietary inclusion of *Camelina sativa* cakes into broiler quails diet on the feed intake and feed conversion ratio.

Item	Experimental groups					
	Control	Calena	Pearl	Alan	*P* value	RSD[1]
N.	12	12	12	12		
FI (g/d)						
15−25 d	22.1	22.0	22.2	21.9	0.5402	0.56
25−35 d	35.4[b]	36.9[a]	36.9[a]	36.0[ab]	0.0177	1.33
15−35 d	28.8	29.5	29.6	28.9	0.0685	0.87
FCR						
15−25 d	2.76[B]	3.15[A]	3.11[A]	3.04[A]	<0.0001	0.18
25−35 d	5.91	5.80	5.81	5.72	0.6919	0.40
15−35 d	4.31[B]	4.62[A]	4.59[A]	4.46[AB]	0.0004	0.18
Mortality, %	0.83	1.67	0.83	0.83	0.731	

[1]Residual standard deviation.

[A,B]Means in the same row with different superscript letters differ for $P < 0.01$ and $P < 0.001$.

[a,b]Means in the same row with different superscript letters differ for $P < 0.05$.

Carcass and Breast Meat Traits

The effect of the dietary inclusion of camelina cakes into broiler quail diets on carcass and meat physical traits is displayed in Table 6. Results highlighted that slaughter ($P < 0.05$) and carcass ($P < 0.05$) weights were penalized when Calena variety was used compared to the Control diet, while Pearl and Alan varieties provided intermediate values. Despite this, carcass yield and breast and leg weights and yields were not affected by the dietary treatments.

Breast meat pHu as well as colorimetric traits were intensely affected by the dietary inclusion of camelina cakes. Meat pHu was higher in the Calena group compared to the Pearl one, with Control and Alan meat showing intermediate values ($P < 0.05$). Meat obtained from quails fed with all camelina cakes, had a higher lightness value compared to the Control one ($P < 0.001$), while redness value was higher in the Control and Pearl groups compared to the Calena one ($P < 0.01$); Alan showed an intermediate value for this trait. Pearl treatment had the highest yellowness value, while Control, Calena, and Pearl were similar among each other ($P < 0.01$). Breast meat cooking loss was not affected by the camelina cake dietary inclusion and, consequently, the same was observed for the WBSF.

Meat Proximate Composition, Heme-Iron Content, Oxidative Status

The proximate composition of quail's breast meat was partly affected by the dietary inclusion of camelina cake (Table 7). With the cultivar Calena, a higher water content compared to the Control group was observed, while Pearl and Alan treatments displayed intermediate results ($P < 0.05$). Lipids too were affected by the dietary treatments with Calena and Alan quails having leaner breast meat compared to the Control and Pearl being similar to the other 3 treatment groups ($P < 0.01$). Protein, ash and heme-iron contents, as well as meat oxidative status, were similar in all treatment groups ($P > 0.05$).

DISCUSSION

For the first time the cakes obtained from a commercial camelina cultivar (Calena) and 2 new camelina lines (Pearl and Alan) were tested into broiler's quail diets, investigating their effect on live performances, carcass traits and meat quality. The chemical composition of Calena cake is comparable with previous studies (Zanetti et al., 2017, 2021; Zając et al., 2020; Mondor and Hernández-Álvarez, 2021). However, the present research also highlighted that the improved lines (Pearl and Alan) displayed different chemical composition to Calena, especially Alan, which was the richest in crude

Table 6. Effect of the dietary inclusion of *Camelina sativa* cakes into broiler quails diet on carcass and meat physical traits.

	Experimental groups					
Item	Control	Calena	Pearl	Alan	*P* value	RSD[1]
N.	60	62	66	62		
Slaughter weight, g	255[a]	246[b]	252[ab]	248[ab]	0.0463	19.5
Carcass weight, g	169[a]	163[b]	168[ab]	165[ab]	0.0320	13.9
Carcass yield, %	66.5	66.2	66.9	66.6	0.5617	2.83
Breast weight, g	55.8	53.6	53.3	52.5	0.0538	6.75
Breast yield, %	32.9	32.9	31.7	31.8	0.0638	2.75
Legs, g	41.3	40.0	40.2	40.0	0.2570	4.03
Legs yield, %	24.4	24.6	23.9	24.3	0.0905	1.62
Breast:						
pHu	5.64[ab]	5.68[a]	5.63[b]	5.67[ab]	0.0108	0.10
L* value	48.7[B]	50.5[A]	50.1[A]	50.8[A]	<0.0001	2.09
a* value	5.63[A]	4.81[B,b]	5.51[AB,a]	5.3[AB]	0.0039	1.34
b* value	0.37[AB,b]	0.30[B]	0.99[A,a]	0.24[B]	0.0018	1.23
N.	14	14	14	14		
Cooking loss, %	22.5	24.2	25.0	23.5	0.0973	2.61
WBSF[2], N	11.1	10.8	10.8	11.3	0.6809	1.43

[1]Residual standard deviation.
[2]Warner Bratzler shear force.
[A,B]Means in the same row with different superscript letters differ for $P < 0.01$ and $P < 0.001$.
[a,b]Means in the same row with different superscript letters differ for $P < 0.05$.

protein and the poorest in ether extract, crude fiber and gross energy. Pearl cake, instead, displayed the highest ether extract and gross energy contents (Table 2). This variability highlights a technical challenge related to camelina cake utilization in feed formulations since, from the practical point of view, a feedstuff with a relatively homogeneous chemical composition is required for industrial-scale applications. The variability of camelina cake chemical composition is attributable to 2 main factors: the known intrinsic heterogeneity in the chemical composition of the camelina seed depending on cultivar, sowing time, seasonal variability across years, and pedoclimatic conditions (Angelini et al., 2020; Walia et al., 2021; Zanetti et al., 2021), and the mechanical pressing step, that allows to obtain the oil fraction and the residual cake, which is not a standardized procedure yet.

Overall live performance and mortality of the growing quails of the present study were in line with available data on this poultry species (Bulbul et al., 2015; Cullere et al., 2016). However, from results it also clearly emerged that camelina cakes penalized the body weight gain and live weight of broiler quails in the first phase of the cycle (15−25 d), while the same groups of quails recovered in the second phase (25−35 d) mainly thanks to a higher feed intake. All this negatively reflected on the farming efficiency of camelina-fed quails, as highlighted by the results of the FCR in the first phase and considering the whole farming period. Among the antinutritional factors of camelina, glucosinolates seem the main negative player in this sense: after ingestion, they are hydrolyzed by both myrosinase enzyme present in plant and endogenous myrosinase produced by the animal's intestinal microflora, yielding to toxic breakdown products, including goitrin, isothiocianates, thiocianates, or nitriles. These compounds interfere with thyroid and liver function ultimately leading to reduced performance and/or undesired physiological effects, depending on dietary concentration and feeding duration (Kempen, 1994; Campbell and Schöne, 1998). Calena showed the most mediocre results when quails were fed this cake. Pearl is the line selected for enhanced ω-3 fatty acids proportion, therefore no remarkably different productive outcomes from the Calena cake could be expected. Differently, Alan line has been improved by classical breeding to reduce glucosinolates content. For this reason, outcomes comparable to the Control group were initially hypothesized, but this was only partly confirmed by experimental findings: Alan quails performed slightly better than Calena and Pearl ones but worse than the Control, thus highlighting that more research on the genetic selection of this camelina line is required before being satisfactorily incorporated into feed formulations for broiler quails at 15% inclusion level. In quantitative terms, the amount of glucosinolates of Alan was higher than that reported by Lolli et al. (2020) using the same line; probably, the different climatic conditions and geographical location of cultivation affected the

Table 7. Effect of the dietary inclusion of *Camelina sativa* cake into broiler quails diet on the proximate composition (g/100 g meat), heme-iron content (mg/100 g meat), and oxidative status (TBARs: mg MDA/kg meat) of breast meat.

	Experimental groups					
Item	Control	Calena	Pearl	Alan	*P* value	RSD[1]
N.	12	12	12	12		
Water	75.1[b]	75.6[a]	75.5[ab]	75.3[ab]	0.0170	0.42
Protein	21.7	21.5	21.6	21.8	0.0571	0.35
Lipids	2.07[A,a]	1.54[B]	1.80[AB]	1.66[AB,b]	0.0051	0.36
Ash	1.37	1.35	1.35	1.41	0.2246	0.08
Heme-iron	8.96	8.22	8.44	9.15	0.8943	3.08
TBARs	0.67	0.67	0.68	0.67	0.8680	0.02

[1]Residual standard deviation; MDA = malondialdehyde; TBARs = thiobarbituric acid reactive substances.
[A,B]Means in the same row with different superscript letters differ for $P < 0.01$.
[a,b]Means in the same row with different superscript letters differ for $P < 0.05$.

glucosinolates content of this breeding line. Therefore, it should also be pointed out that probably not all the negative effects could be attributable to the glucosinolates content. In fact, results of the present research highlighted that glucosinolates were more abundant in Pearl line cake and Pearl diet, respect to Calena and Alan cakes and diets. Calena cake, instead, exhibited the highest content of trypsin inhibitor (14.3 TIU/mg) whereas Pearl cake had the lowest (11.9 TIU/mg), confirming the findings of Pozzo et al. (2022). Despite this, no relevant differences were detected between the experimental diets, where the trypsin inhibitor content was slightly higher than 4.0 TIU/mg, and not detectable in the Control diet (Table 3). Regarding the other antinutritional compounds, analyses indicated that condensed tannin content was the highest in Calena diet (0.37 μgCE/mg), thus providing a further indication to justify the worst productive outcomes exhibited by quails fed with this camelina line.

Existing literature on poultry highlighted that increasing inclusion rates of camelina cake into Japanese quail diets (5−35 d of age) worsened FCR (Bulbul et al., 2015). Similarly, it led to a linear reduction of nutrient digestibility into broilers' chicken diet (1−42 d of age), but without affecting chicken's health status (Oryschak et al., 2020). In another study, broiler chickens fed with a 15% full-fat unprocessed camelina cultivar Luna (21 −42 d of age) had comparable body weight gain compared to those receiving the control diet, despite a remarkably lower ether extract digestibility (Zając et al., 2020). Young turkeys (1−28 d of age) fed with 5, 15, or 20% camelina cake showed a progressive reduction in body weight and worsening in FCR compared to the control (Frame et al., 2007). Again, 3-wk-old broiler chickens fed either with 10 or 20% dietary inclusion of camelina cake exhibited a remarkable reduction in feed intake and weight gain compared to a reference diet (Pekel et al., 2015), as a result of poor energy and nitrogen utilization by broiler chickens. This could be due to the high viscosity observed in jejunal digesta as well as the total glucosinolates content of camelina meals. In general, results of the present research seem to confirm that birds, in the first growth phase, are more sensitive to glucosinolates compared to older ones (Tripathi and Mishra, 2007), therefore suggesting that low inclusion levels of this oilseed cake should be adopted in the first phase of the rearing cycle. These results highpoint a key consideration related to the economic sustainability and thus possible large-scale feed applications of camelina cake into commercial feed formulations: camelina is surely an oilseed crop with a promising potential in improving the sustainability of the livestock sector, thanks to its unique agronomic characteristics and multiple end-uses, and the good adaptability to all European climates and soils (Zanetti et al., 2021). However, a key prerequisite is that the ideal productivity target of the intended animal species should be achieved to ensure the economic revenue of farmers. To this regard, literature results available up to now highlight the necessity to carry out further research aiming at establishing species-specific and age-specific threshold limits for camelina cake utilization into poultry feeding: this would represent a fundamental step to allow the practical application into commercial feed formulations.

The negative effect of the camelina cakes on quail carcass weight observed in the present research were explained by the results observed on live performance, as it was also found in previous research (Pekel et al., 2015).

Physical quality of the breast meat (*pectoralis major* muscle) showed to be remarkably affected by the dietary incorporation of the 3 camelina cakes: the highest pHu recorded for Calena breast muscle could be linked to the worst growth performance, since this could have affected glycogen storage in the muscle, thus affecting pH lowering and thus ultimate value (Sawyer et al., 2008). Despite this significant difference, in absolute terms the pHu values of the experimental groups could be considered optimal and typical for quail breast meat cut (Cullere et al., 2016). Colorimetric characteristics were intensely affected by the dietary inclusion of camelina cakes. On the one hand pH could have played a role in this, given its well-known link with meat color (Wideman et al., 2016), but it should also be considered that camelina seed is rich in antioxidants such as phenolic acids, flavonoids, tocopherols, and xanthophylls, which showed to affect camelina oil color (Zanetti et al., 2021). As pHu differences among groups were negligible and given the key role of poultry ration on meat color, it was hypothesized that camelina antioxidant compounds were probably the main factors in affecting meat color. Unfortunately, at present no other data are available regarding the impact of camelina cake on breast meat pHu and color traits. For this reason, further research would be desirable to understand if the pH and colorimetric changes are a constant and, if so, to what extent they deserve attention.

The proximate composition of quail breast meat was in line with literature data (Cullere et al., 2018; Orczewska-Dudek and Pietras, 2019), highlighting once more the interesting nutritional profile of this meat-type poultry species. The most distinguishable qualitative trait of quail meat compared to chicken meat seems the heme-iron content, definitively higher and quantitatively halfway between white and red meat species (Lombardi-Boccia et al., 2002). Results of the present research highlighted that Calena inclusion increased the water content and reduced the lipid one compared to the Control, and this found confirmation in previous research on poultry species (Rebole et al., 2002; Zając et al., 2020). This finding, yet positive from a consumer's nutritional perspective, could be hypothetically attributed to a lower crude fat digestibility (Oryschak et al., 2020; Zając et al., 2020). Preliminary results of an *in vivo* digestibility trial (personal communication) related to the present work, pointed out that Calena diet negatively impacted the apparent digestibility of nutrients and energy compared to the Control diet, with the sole exception of the protein digestibility. Furthermore, with a high unsaturation degree of lipids in the diet their

β-oxidation increase leading to a decrease in fatty acid synthesis and deposition; this physiological pattern promotes the absorption of circulating fat by muscle tissue and its use as a direct source of energy rather than being stored (Sanz et al., 2000).

CONCLUSIONS

Results of the present research indicate that camelina cake can be considered an alternative feedstuff for broiler quails' feed formulations, without compromising carcass traits and meat quality. However, a 15% inclusion level seems excessive as live performances were impaired in all camelina groups, especially Calena. Based on these findings, the inclusion level in broiler quail's diets is a research topic that is worth to be thoroughly investigated in the future, also considering the period of administration. Furthermore, it would also be necessary to further work on the genetic improvement of the crop to further reduce the content of antinutritional factors. Finally, an in-depth evaluation of meat chemical characteristics, above all the FA profile, and sensory traits should be adequately investigated, the latter being relevant for both consumers' acceptance as well as for marketing purposes.

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DISCLOSURES

The authors declare that they have no conflicts of interest to report.

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